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Comparative life cycle assessment of margarine and butter consumed in the UK, Germany and France

Katarina Nilsson · Anna Flysjö · Jennifer Davis · Sarah Sim · Nicole Unger · Simon Bell

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Abstract
Purpose The goal of the study was to compare the environmental impact of butter and margarine. Altogether, seven products were studied in three European markets: UK, Germany and France.
Methods The approach used for the analysis is descriptive (attributional) LCA. The SimaPro software PRé 2007 was used to perform the calculations. Data for the production chain of the margarine products (production of raw materials, processing, packaging and logistics) were compiled from Unilever manufacturing sites, suppliers and from literature. The edible oil data inventories have been compared with those in proprietary databases (ecoinvent and SIK food database) and they show a high degree of similarity. For the butter products, data on milk production and butter processing were taken from various published studies for the countries of interest. Sensitivity analyses were conducted for a number of parameters (functional unit, allocation method, impact of using different oil, milk and dairy data, impact of estimating GHG emissions from land use change for certain oils) in order to evaluate their influence on the comparison between margarine and butter. The sensitivity analyses demonstrate that the initial results and conclusions are robust.
Results The results show that margarine has significantly lower environmental impact (less than half) compared to butter for three impact categories global warming potential, eutrophication potential and acidification potential. For primary energy demand, the margarines have a lower impact than butter, but the difference is not as significant. Margarines use approximately half of the land required used for producing the butter products. For POCP, the impact is higher for the margarines due to the use of hexane in the oil extraction (no similar process occurs for butter).
Conclusions The margarine products analysed here are more environmentally favourable than the butter products. In all three markets (UK, DE and FR) the margarine products are significantly better than the butter products for the categories global warming potential, eutrophication potential and acidification potential. These findings are also valid when comparing margarines and butters between the markets; for this reason they are likely to be of general relevance for other Western European countries where similar margarine and butter production systems are found.

Keywords Butter · Carbon footprint · Fat · Life cycle assessment · Margarine · Spreads

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K. Nilsson (✉) · A. Flysjö · J. Davis
SIK—The Swedish Institute for Food and Biotechnology,
P.O. Box 5401, 40229 Gothenburg, Sweden
e-mail: kn@sik.se

S. Sim · N. Unger
Unilever—Safety and Environmental Assurance Centre,
Unilever,
Sharnbrook MK40 1LQ, UK

S. Bell
Unilever House, Unilever UK,
Springfield Drive,
Leatherhead KT22 7GR, UK

Present Address:
A. Flysjö
Arla Foods amba,
Skanderborgvej 277,
8260 Viby J, Denmark

1 Introduction

Margarine was first developed more than 100 years ago as an inexpensive alternative to butter and it soon captured a substantial segment of the market. For companies producing products such as margarine, spreads[1] and butter, long-term growth is likely to be fuelled by a focus on health and nutrition, but also on their commitment to manage their environmental impacts. Increasingly, companies must find more sustainable ways of doing business; this is emphasised by the growing interest in carbon footprint standards and labelling schemes internationally (e.g. PAS 2050 and the Carbon Trust label in the UK, Grenelle de l'environnement in France and the Product Carbon Footprint System in Japan). A number of life cycle assessment studies on margarine and milk have already been conducted (e.g. Shonfield and Dumelin 2005; Nielsen et al. 2003; Cederberg and Flysjö 2004; Thomassen et al. 2008) but to our knowledge, few studies have examined the impacts of butter across the whole life cycle (Nielsen et al. 2003). This paper describes research undertaken to analyse the environmental impact of margarine and butter products sold in selected European markets to understand how these products compare. Such studies are also useful for manufacturers to identify opportunities to reduce their own respective environmental impacts, e.g. through product and packaging optimisation or new product innovation.

2 Method

The approach used for the analysis is descriptive (attributional) LCA, i.e. it is an accounting LCA, documenting current activities, often approximated by past (most recent) data (as described in Section 2.5). The SimaPro software (PRé 2007) was used to perform the calculations.

Sensitivity analyses were conducted for a number of parameters (functional unit, allocation method and impact of using different oil, milk and dairy data) in order to evaluate their influence on the conclusions of the comparison between margarine and butter. Biogenic carbon is not included in this study. The carbon captured by plants while growing is assumed being released when the final product is consumed, thus the uptake and release is equal and therefore a plus minus zero assumption is made for the biogenic carbon. However, in the discussion a sensitivity analysis is made based on biogenic carbon emissions from direct land use change associated with palm oil cultivation (Section 4).

[1] Traditional margarine has an 80% fat content; products which contain lower fat levels cannot be labelled 'margarine', but are instead referred to as 'spreads' for on-pack labelling. However, the words spreads and margarine are used interchangeably in this paper.

An external review according to ISO 14 040 and 14 044 (ISO 2006a,b) was performed on the study by ART (Agroscope Reckenholz-Tänikon Research Station) Zurich, Switzerland.

2.1 Products studied

Two products, one margarine product and one butter product, were studied in three markets: UK, Germany and France. For the UK market a spreadable butter containing 25% vegetable oil was also included. In total seven products were included in the analysis. The products were selected as they are representative of the biggest selling stock keeping units in the three markets. The compared products are given in Table 1.

2.2 Environmental impacts considered

The following impact categories were included in the analysis, selected on the basis of their importance to food production systems: primary energy use (PE), global warming potential 100 years (GWP, sometimes also referred to as carbon footprint), eutrophication potential (EP), acidification potential (AP), photochemical ozone creation potential (POCP). The characterisation method used in the study was CML 2001 (Guinée et al. 2002)—available in the SimaPro software, (PRé 2007). However, the method was adjusted to include the latest GWP characterisation factors for methane (25 g CO_2-eq/g CH_4) and nitrous oxide (298 g CO_2-eq/g N_2O) published by the IPCC in 2007(IPCC 2007). For primary energy use, the cumulative energy demand (CED) was calculated according to the method published by ecoinvent (Frischknecht et al. 2003), including energy from the following categories: fossil, nuclear, biomass, wind, solar, geothermal and hydro. The CED is the total (primary) energy use, based on the upper heating value (or gross calorific value).

Impacts related to land use (e.g. soil degradation) and pesticide application (e.g. toxicity effects) are also relevant for food production systems, though it was not possible to assess these impacts here due to lack of data and/or agreed or robust methodological approaches. However, land occupation (m^2*a) was included as a crude proxy for potential land use effects.

2.3 Functional unit

This study focuses on margarine and butter used as a spread, i.e. to act as a barrier to stop sandwich fillings making the bread go soggy; to make the cheese, ham or other toppings stick to the bread; or simply to improve the eating experience by making the bread less dry. We believe the same amount of either margarine or butter is used to fulfil this function. The recommended serving size for margarine is 10 g (IMACE 2008); this is also assumed for

Table 1 Products compared in the study

Market	Margarine	Spreadable butter	Butter
UK	38% fat	80% fat (25% is rapeseed oil)	80% fat
	Sold in 500 g units	Sold in 500 g units	Sold in 500 g units
	Polypropylene tub	Polypropylene tub	Butter wrapper
	Produced in: UK	Produced in: Denmark	Produced in: Denmark
Germany	70% fat		80% fat
	Sold in 500 g units		Sold in 250 g units
	Polypropylene tub		Butter wrapper
	Produced in: Netherlands/Germany (50/50)		Produced in: Germany
France	60% fat		80% fat
	Sold in 500 g units		Sold in 250 g units
	Polypropylene tub		Butter wrapper
	Produced in: Spain		Produced in: France

butter. Thus, the functional unit of the study is 500 g of packaged butter/margarine intended for use as a spread, delivered to the manufacturer's distribution centre in each country (i.e. UK, Germany and France). The use of these products for any other purpose (e.g. cooking or the provision of nutrients/calories) is not considered. However, in order to understand whether the difference in environmental impact between the products is due to the type of fat used (animal or vegetable), or to the differing fat content of these products, a sensitivity analysis is presented in Section 4. This shows the results related to the amount of fat in each product, i.e. 500 g of fat contained in packaged butter/margarine delivered to the manufacturer's distribution centre in each country.

2.4 System boundaries

The system boundary is drawn from the cradle to the main Unilever distribution centre in each country for both the

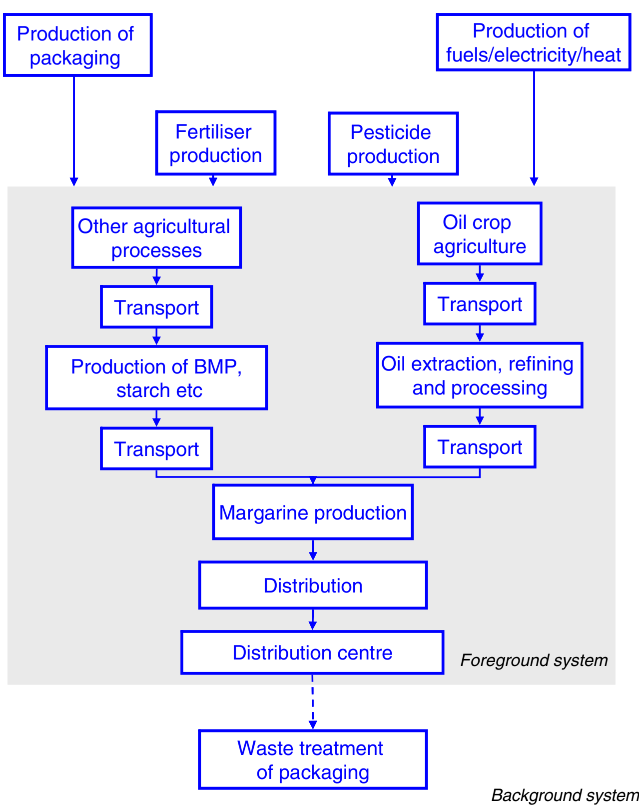


Fig. 1 Schematic flowchart of production of margarine

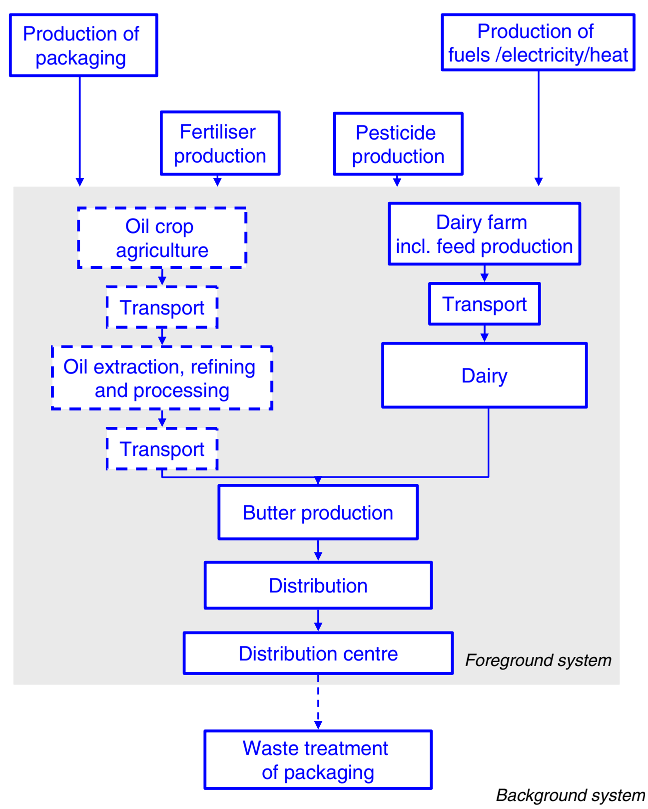


Fig. 2 Schematic flowchart of production of butter

Table 2 Composition of the three margarine products

Ingredients	UK (38% fat content) % of mass	Germany (70% fat content) % of mass	France (60% fat content) % of mass
Rapeseed oil	–	36.18	20.86
Sunflower oil	25.50	3.48	17.88
Palm kernel oil	–	–	5.96
Maize oil	–	3.48	–
Rearranged mixture of palm and palm kernel oil	6.65	26.44	14.90
Linseed oil	5.93	–	–
Modified tapioca starch	2.75	–	–
Salt	1.30	–	–
Sweet buttermilk powder	–	–	0.50
Water	57.20	29.15	39.01
Total	99.33	98.73	99.11

Source: Unilever (2008)

margarine and the butter products (Figs. 1 and 2). The starting point of the studied system is extraction of raw materials for the production of ingredients, materials and fuels required for the production of butter and margarine. In the case of margarine, the agricultural stage includes the production of oil seeds and associated farm inputs. For butter, the agricultural stage incorporates all major farm activities and emissions at farm level, including the production of feed for the dairy cows (both produced on-farm and purchased) as well as other farm inputs. Oil production is displayed in dotted boxes in Fig. 2, only one of the butter products (the spreadable butter) contains vegetable oil (25%). Storage at the distribution centre, transport to the retailer and storage at the retailer and household stages are not included (these are assumed to be similar for all products studied). However, waste management of the packaging is included even though this takes place beyond the distribution centre, to ensure a fair comparison of the different products.

2.5 Data and sources

Data for the production chain of the margarine products (production of raw materials, processing, packaging and logistics) were compiled from Unilever[2] manufacturing sites (Unilever 2008), suppliers (Unilever suppliers 2005–2008) and from literature sources (Corley and Tinker 2003). The edible oil data inventories have been compared with those that can be found in ecoinvent database (2007) and also in SIK's database (unpublished) and there is a high degree of similarity. These data are considered to be recent (ranging from 2004 to 2007) and to represent the studied systems well. Data on butter milk powder was taken from Högaas Eide (2002) and Nielsen et al (2003).

[2] Unilever is one of the world's leading suppliers of fast moving consumer goods (Foods and Home and Personal Care Products).

Data on milk production for the butter products have been taken from published studies. Data on milk production for UK butter (which, in this case, is produced in Denmark) is taken from the Danish food database (Nielsen et al. 2003). These data represent eight typical Danish dairy farm types in 1999, which accounts for 85% of the total milk produced in Denmark. Since results are calculated based on consequential LCA in the Danish food database, here, raw data for one farm type (representing 43% of total milk production in Denmark) were used to model the milk production in Denmark based on attributional LCA (as this is the chosen method in this study). Data for milk production in Germany are taken from Haas et al. (2001), comparing intensive, extensive and organic grassland farming in southern Germany (Allgäu region); only the results for intensive grassland farming were used. The milk production in France is based on an LCA study comparing conventional and organic milk production at farm level (van der Werf et al. 2009). In total, 47 dairy farms were studied in the Bretagne area (41 conventional and six organic), but here only the results from the conventional farms have been used. The data used for milk production are the best available and are considered to be of good quality to fulfil the purpose of this study. Data for the processing of butter were collected from the Danish food database (Nielsen et al. 2003), which gives data for a large-scale manufacturing facility. These processing data are considered representative of butter production in the studied countries and have therefore been used for all three butter products. In order to consider country-specific conditions the data for electricity and fuel mixes were adapted. In addition the main butter production sites/regions in each of the studied countries were identified and transport distances were calculated from these production sites/regions to the distribution centre in each country (the same distribution centre as for the margarine products). Specific packaging data according to the biggest selling stock keeping units in the three markets have been

Table 3 Key inventory data for production of rapeseed oil, sunflower oil, palm oil and palm kernel oil (source: Unilever suppliers (2005–2008); Corley and Tinker (2003))

Description	Rape seed oil	Sunflower oil	Palm oil	Palm kernel oil
Crop production				
General				
Mass of harvested crop [kg/ha/year]	4,250	1,500	25,000	25,000
Diesel fuel consumed [kg/ha/year]	59.5	38.9	168.1	168.1
Pesticide active ingredient applied [kg/ha/year]	0.535	1.03	10.6	10.6
Fertilisers				
Ammonium sulphate [kg-N/ha/year]	72		22	22
Lime fertiliser [kg-CaO/ha/year]	400			
Potassium chloride [kg-K_2O/ha/year]	241	7.5	170	170
Urea fertiliser [kg-N/ha/year]	136	55		
Other NP or NPK fertiliser (assumed to monoammonium phosphate) [kg-N/ha/year]		45		
Phosphate rock [kg-P_2O_5/ha/year]		14.2	20.1	20.1
Triple superphosphate [kg-P_2O_5/ha/year]	59.5			
Nitrogen obtained from other sources [kg-N/ha/year]			26.36	26.36
Oil extraction				
Crop input to crushing mill [kg]	2,500	2,500	4,545	4,545
Crude oil production [kg]	1,000	1,000	1,000	1,000
Meal production [kg]	1,500	1,500		
Palm kernel production (contains 50% oil) [kg]			227	227
Shell produced during oil extraction process [kg]			3,318	3,318
Electricity [MJ]	500	500		
Hexane [kg]	2	2	2	2
Steam [MJ]	1,680	1,680		
Refined oil production				
Acid oil co-product [kg/tonne]	36.85	37.95	61.46	67.2
Activated carbon [kg/tonne]	2.02	5.05		
Bleaching earth [kg/tonne]	7.06	3.03	7.45	4.3
Electricity [kWh/tonne]		54.8	47.91	48.07
Diesel Fuel [kg/tonne]	8.02	8.02	8.48	8.53
Crude oil input [kg/tonne]	1,046.46	1,046.84	1,064.17	1,068.8
Steam [kg/tonne]	265.91	266.01	214.19	214.67

used for each product. Average data have been used for processes occurring in the background system (see Figs. 1 and 2; e.g. transport and energy); these were mainly taken from ecoinvent (2007). The composition of the margarine products is given in Table 2. Ingredients less than 0.5% of mass have been excluded. Because lack of inventory data the following assumptions have been made: potato starch (ecoinvent 2007) has been used instead of tapiocha starch, rapeseed oil instead of linseed oil but with an additional contribution of a transport from Canada, for the maize oil maize corn cultivation (ecoinvent 2007) has been used with pressing and refining processing data from the palm oil. Some key data are given in Tables 3 and 4 for oil and margarine production and Tables 5 and 6 for milk and butter production. The fat content for butter is 80%, butter milk 0.4%, cream 40%, skim milk in Denmark and Germany

Table 4 Energy use for production of the different margarine products (source: Unilever 2008)

Product	Unit	Electricity (from grid)	Gas	Light fuel oil	Total
UK margarine	GJ/t	0.499	0.828	0	1.327
DE margarine	GJ/t	0.374	0.628	0.005	1.01
FR margarine	GJ/t	0.295	0.749	0.016	1.06

Table 5 Inventory results: emissions for 1 kg of milk at farm gate

Emission	Denmark (g per kg milk)	Germany (g per kg milk)	France (g per kg milk)
CO_2	270	180	170
CH_4	25	34	29
N_2O	2.3	1.4	1.3
SO_2	0.71	0.15	1.6
NO_X	1.8	1.2	1.9
NH_3	7.1	9.4	4.0
NO_3	72	14	68
PO_4	0.91	2.7	0.19

No allocation between milk and meat is performed in this Table (i.e. here, all emissions are allocated to the milk; source: Nielsen et al. 2003; Haas et al. 2001; van der Werf et al. 2009). Please note that allocation has been performed in the analysis, according to Table 6

0.05% and skim milk in France 0%. This gives slight differences in the amount of milk needed for producing one kg of butter in the different countries as shown in Table 6.

2.6 Allocation

There are several processes in the systems which generate more than one useful output, e.g. extraction of vegetable oil which generates both oil and meal and rearing of dairy cows which yields both milk and meat. For all multi-output processes we employ economic allocation to distribute the environmental impact between the co-products. This was the allocation method which could be applied to all activities for both margarines and butter. However, we performed sensitivity analyses with other allocation methods in order to check the robustness of the results including: mass allocation for the vegetable oil extraction, allocation according to the causality between the supply of energy and protein to cover the dairy cow's milk production (allocated to the milk) and her maintenance and pregnancy (allocated to the meat) according to Cederberg and Stadig (2003). For dairy, an alternative allocation method according to the allocation matrix developed by Feitz et al. (2007) was also applied; this is based on milk solids content and average resource use (e.g. energy, water) of the different dairy products. Table 7 gives a summary of the allocation factors that have been used in the study.

Table 6 Inputs and outputs (unallocated) used for modelling the butter production at the dairy

Dairy sites		Denmark	Germany	France[a]
Inputs				
Milk	kg	18.90	18.90	18.70
Electricity	MJ	3.79	3.79	3.75
Heat from natural gas	MJ	3.35	3.59	3.59
Heat from oil	MJ	0.37	0.13	0.092
Water	kg	14.12	14.12	13.98
Outputs				
Skim milk	kg	16.89	16.89	16.69
Butter	kg	1	1	1
Butter milk	kg	1.01	1.01	1.01
Waste water to treatment	kg	14.12	14.12	13.98

[a] The fat content in the French skim milk is lower than for the Danish and German skim milk

Table 7 Allocation factors employed in the study

Impact allocated to	Percentage impact (economic allocation)	Percentage impact (alternative allocation)
Extraction sunflower oil		
Crude oil	82	40
Cake	18	60
Extraction rapeseed oil		
Crude oil	77	40
Cake	23	60
Extraction palm oil/palm kernel oil		
Palm oil	85	90
Palm kernel oil	15	10
Milk UK (DK)	87	85
Milk FR	82	85
Milk DE	90	85
Butter	33	22[a]

[a] For raw milk, specific allocation factors are then used for electricity (12%), thermal energy (20%) and water (12%)

For the waste management of packaging, a cut-off at recycling has been applied, i.e. we assume that the cost and benefit of the recycling is allocated to the life cycle in which the material is used next. If recycled material is used as an input to the system, this is taken into account. The reason for this assumption is that the use of recycled material is more likely to drive recycling than the supply of recyclate. Incineration of packaging is taken into account in that emissions are included in the analysis, allocated to the waste disposal stage. However, any waste heat that is recovered is ascribed to the life cycle in which the energy is used (there considered as 'free' energy). In this way, the production of waste is not associated with 'credits'.

3 Results

There are large differences between the environmental impact of butter and margarine, independent of market (Table 8 and Fig. 3).

The difference between the margarine and butter products is least significant when considering energy use

Table 8 Environmental impact of the margarine and butter products per FU

	PE	GWP	EP	AP	POCP	Land competition
	MJ	kg CO_2 eq	kg PO_4 eq	kg SO_2 eq	kg C_2H_4 eq	m^2a
UK margarine	9.1	0.55	0.0070	0.0078	0.00031	2.3
DE margarine	11	0.66	0.0066	0.012	0.00062	1.6
FR margarine	13	0.83	0.0083	0.012	0.00052	2.3
UK butter	21	4.8	0.030	0.038	0.00011	5.9
UK spreadable	20	3.7	0.023	0.032	0.00028	4.7
DE butter	15	4.5	0.022	0.046	0.000045[a]	4.0
FR butter	16	3.6	0.022	0.025	0.000041[a]	4.4

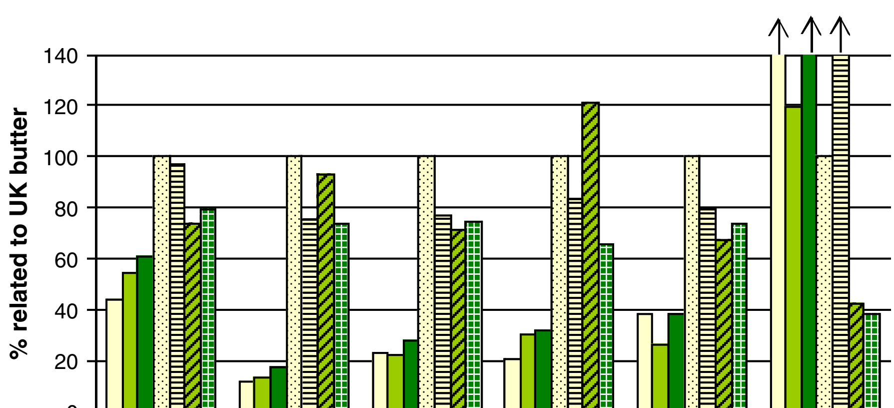
[a] Contribution from the dairy farm is not included due to lack of data

but in all countries the margarine products require less energy than butter products. In the UK, margarine requires about 50% less energy; for Germany the difference is about 25% and for France, 20%. UK butter has the highest energy use, whilst the UK margarine is the product with the lowest energy requirement (mostly due to the low fat content).

The largest difference between butter and margarine occurs for the GWP impact category. The carbon footprint of the margarine does not exceed 25% of that for butter, independent of the country. For both AP and EP, the butter products contribute at least twice as much as the margarines, in all three countries. The agricultural land occupation for the margarines is smaller in comparison to the land use for the butters (around half). The reason, of course, is that more land is needed to produce the feed for the cows (i.e. concentrate feed, grains and grazing), than is needed to produce the vegetable oil crops for the margarines.

The only environmental impact that is higher for the margarine products compared to butter is POCP. This is due to the use of hexane in the oil extraction (no similar process occurs in butter production). For margarines, the fat content plays an important role for this impact; the more oil used in the recipe, the more hexane required for extraction. Thus the POCP contribution is highest for the FR margarine, which has the highest fat content and lowest for the UK margarine, which has the lowest fat content. It was not possible to estimate the complete POCP impact for the French and German butter products since data at the farm level was missing. However, when comparing the POCP impact from the UK butter with the margarines the

Fig. 3 The relative difference per impact category for all seven products: margarine has a significantly lower environmental impact than butter for all impact categories shown, both when comparing within and between countries



	PE	GWP	EP	AP	land competition	POCP
UK margarine	44	11	23	20	38	289
DE margarine	54	14	22	30	26	119
FR margarine	61	17	28	32	38	487
UK butter	100	100	100	100	100	100
UK spreadable	97	76	77	83	79	257
DE butter	73	93	72	121	68	42
FR butter	79	74	74	65	74	38

Table 9 Weight of product (g) required to provide 500 g of fat

	UK (g of product)	DE (g of product)	FR (g of product)
Margarine	1,282	718	839
Butter/spreadable	625	625	625

contribution to POCP for the margarines is about five times higher than for UK butter.

Even allowing for results being under- or overestimated by as much as 20% (i.e. to account for potential variability around inventory data), margarine still has a significantly lower environmental impact than butter (around half) for global warming potential, eutrophication potential and acidification potential.

When comparing margarine and butter products in terms of energy use, the difference ranges from 20% to 50% less energy required for the margarine products. Alternative palm oil and sunflower oil data sources (ecoinvent) used for the sensitivity analysis (Section 4) result in a slightly increased energy demand for all margarine products, but they still require significantly less energy than the butter products, i.e. the results are considered robust.

The agricultural stage contributes most to the environmental impact for all products, and is particularly significant when it comes to milk production for butter. The packaging has a smaller influence on the environment compared to the impact from the product, for both margarine and butter. However, the margarine packaging (PP moulded tub and lid) has a higher GWP impact than the butter wrapping (aluminium-laminated paper), representing about 10–20% of the total GWP impact for margarines.

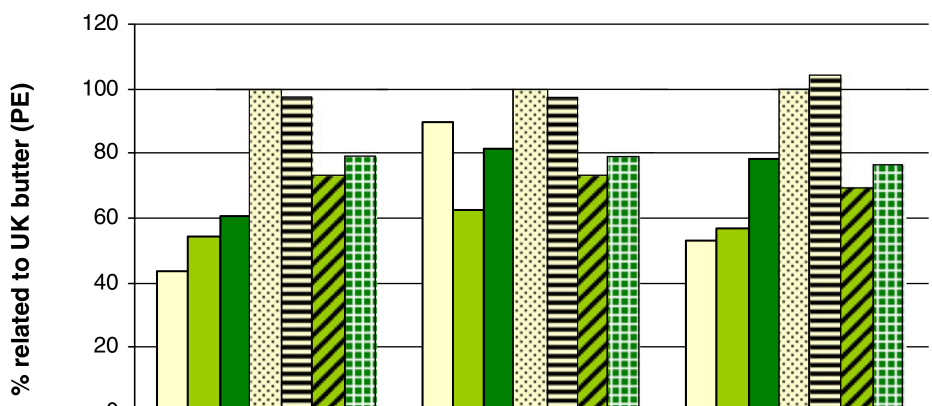
4 Discussion and sensitivity analysis

A variety of sensitivity analyses were performed to verify the robustness of the results. The following parameters were checked in order to see how they affect the comparison between margarine and butter as listed below.

4.1 Fat content (alternative FU)

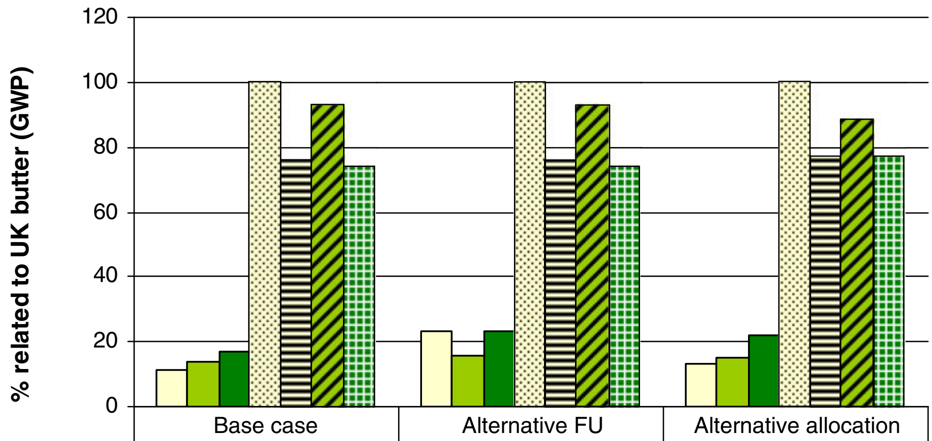
First an alternative FU was analysed based on the fat content of the products in order to determine if the differences in environmental impact for butter and margarine are attributable to the fat content or the type of fat (animal or vegetable). Table 9 shows the amount of product needed to provide 500 g of fat. The increase is the same for all butters (25% more compared to the base case), while it varies for the margarines. When considering the environmental impacts related to 500 g of fat versus 500 g of product, the largest differences are seen for the UK

Fig. 4 Primary energy use, base case compared to results produced with alternative functional unit and allocation method, respectively



	Base case	Alternative FU	Alternative allocation
UK margarine	44	90	53
DE margarine	54	62	57
FR margarine	61	82	78
UK butter	100	100	100
UK spreadable	97	97	104
DE butter	73	73	69
FR butter	79	79	77

Fig. 5 Global warming potential base case compared to results produced with alternative functional unit and allocation method, respectively



	Base case	Alternative FU	Alternative allocation
UK margarine	11	23	13
DE margarine	14	16	15
FR margarine	17	23	22
UK butter	100	100	100
UK spreadable	76	76	77
DE butter	93	93	89
FR butter	74	74	77

margarine due to its low fat content (only half the fat content of butter). The fat content in the DE and FR margarines are closer to the fat content in butter (70% and 60% compared to 80%) and therefore the results in comparison to the base case are not dissimilar. The results for PE and GWP related to the 100% fat content (alternative FU) are shown in the middle section of Figs. 4 and 5, whilst results related to product weight (base case) are shown to the left. The results show that the energy use is somewhat higher or similar for the butter products than the margarines looking within the same country, but the DE butter now requires less energy compared to the UK and FR margarines (see Fig. 4). For contribution to global warming, the butter products still have a higher contribution to global warming than the margarines (see Fig. 5) when compared both within and between countries. Also for EP and AP the results (not shown) are similar to the ones for GWP. In conclusion, even when accounting for the differences in fat content, the margarine products have a significantly lower impact than the butter products, except for energy use, where the difference is small, and land use (not shown) for the UK case. This indicates that the environmental impact of these products is determined by the type of fat used (animal or vegetable) and not just the fat content.

4.2 Allocation methods

Allocation is often one of the more critical methodological choices when conducting LCA studies (e.g. Cederberg and Stadig 2003; Feitz et al. 2007). The effect of using different allocation methods was also analysed here as a second sensitivity analysis. Using an alternative allocation method gave a higher result for the margarines while the butter products showed lower results. Hence, the difference between margarines and butters were somewhat reduced. However, the results still show that butter has, in all cases but two (energy use for DE and FR butter with alternative allocation compared to FR margarine with alternative allocation), a higher energy use and GWP than the margarines (see Figs. 4 and 5). In all cases, i.e. independent of allocation method used, the contribution to global warming is more than three times larger for the butter products compared to the margarines. For eutrophication and acidification too, the comparison between margarine and butter remains unchanged, independent of allocation method used (i.e. margarine has significantly less impact than butter).

4.3 Using alternative data (including land use change) for vegetable oils

A third sensitivity analysis was performed using data from different data sources for the two key vegetable oils, sunflower oil and palm oil. These data were taken from ecoinvent (2007), Schmidt (2007) and SIK's food database (unpublished).

Sunflower oil is the oil with highest GWP and the higher content of sunflower oil in the UK margarine results in a higher carbon footprint for this product. If the dataset for sunflower cultivation is replaced with the data set from

ecoinvent (2007) which has the highest environmental impact of the compared data sources, the GWP result would be 20% higher for the UK margarine, but still it would only represent 19% (instead of 16% as in the base case) of the UK butter contribution to GWP per FU.

For palm oil the impact of a worst case scenario including potential contributions from direct land use change (assuming transformed forest land, 50% in Malaysia and 50% in Indonesia, using data from PAS 2050 (2008)), cultivation on peat soils (assuming that approximately 4% of palm is cultivated on peat, Schmidt 2007) and contributions from the POME waste fraction (Schmidt 2007) in the palm oil and palm kernel oil data was analysed. In this scenario the GWP of the margarine products still does not exceed 50% of the GWP from the "best" butter (French).

4.4 Comparison of data on milk production with other sources

Since data on milk production for the countries of interest were taken from the literature, a comparison with other studies on milk was performed as a fourth sensitivity analysis. Comparing results from other European milk studies at farm gate (Casey and Holden 2005; Cederberg and Mattsson 2000; Cederberg and Flysjö 2004; Cederberg et al. 2007; Hospido 2005; Thomassen et al 2008; Williams et al. 2006) shows a range between 0.9 kg CO_2-eq (Cederberg and Flysjö 2004) to 1.4 kg CO_2-eq (Thomassen et al. 2008) per kilogram of milk. All figures are at farm gate; Cederberg, Casey and Holden and Hospido refer to energy corrected milk, Thomassen to fat and protein corrected milk and Williams it is not stated. The data used in this study gave results (1.37 kg CO_2-eq for DK, 1.29 kg CO_2-eq for DE and 1.04 kg CO_2-eq for FR milk at farm gate), which are within this range (0.9–1.4 kg CO_2-eq).

4.5 Energy use at dairy for butter production

The final sensitivity assessment was conducted to check the effect of altering the energy use data for the dairy manufacturing site. Since data for dairy manufacturing are based on a large-scale plant, they may not be representative for Europe (e.g. in France a lot of small-scale manufacturing sites exists). For this reason, the energy use was doubled (assuming inefficiencies of small-scale production), resulting in a 14% increase in energy use and a 5% increase in GWP for UK butter per FU. Similar increases were shown for the other butter products.

In summary, two major factors determine the environmental impact of the butters and margarines:

1. The origin of the fat (milk or vegetable and for the latter which type of vegetable oil)
2. The fat content.

This is because for all impact categories and all products, the agricultural stage contributes most to the overall impact of the product (with the exception of POCP for margarine). The environmental impact of milk at the farm gate is higher than the impact of producing oil crops, mainly due to the impact of methane emissions from enteric fermentation in cows' digestive systems, the production or feed for dairy cows and also the emissions from manure handling. There is also a difference in the environmental impact of the different vegetable oils used in the margarines; sunflower oil has a higher impact than the other oils. In fact this can override much of the benefit offered by lower fat content. This can clearly be seen for the UK margarine which has a fat content of only 38%. However, because this margarine contains a high level of sunflower oil, the result for the impact categories EP and land use is higher than that for the other two margarines, in spite of their higher fat contents of 60% and 70% (see Fig. 3).

5 Conclusions

The margarine products analysed here are more environmentally favourable for the specified impact categories than the equivalent butter products. In all three markets (UK, DE and FR) margarine products are significantly better than butter products for the impact categories: Global warming potential, eutrophication potential and acidification potential. Also primary energy use and land occupation are less for margarine than butter, though not as significant as for the other impact categories. These findings are also valid when comparing margarine and butter between the markets; for this reason they are likely to be of general relevance for other Western European countries where similar margarine and butter production systems are found.

An extensive sensitivity analysis was performed, showing that the results are robust, particularly for GWP, EP and AP. However, for primary energy where the difference between margarine and butter was less pronounced in the base case, this difference was partially eroded when the FU was changed or when an alternative allocation method was used.

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